Study of Iso-Dense Bias (IDB) sensitivity to Laser Spectral Shape at the 45nm Node

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ABSTRACT

Here we present both simulation and experimental results that show the effect of changes in laser light source bandwidth (E95) on CD Iso-Dense Bias. For the 55nm Technology Node Device, we have shown that E95 stability of less than 0.11pm is required in order to maintain OPE variation to within 2nm. In addition, we also verified another method to adjust for OPE variations that occur when E95 fluctuates. The Contrast Adjustment method is an effective function to adjust for OPE variation due to E95 fluctuation; it has been shown to maintain OPE variation less than 1.5nm. Furthermore, for the 45nm Technology Node Device, we have demonstrated that E95 stability of less than 0.07pm is required to maintain OPE variation to within 1nm. The bandwidth performance of the latest laser light source exhibits E95 stability less than 0.03 pm, thereby showing that the OPE variation due to E95 can be kept to under 1nm.

Keywords: Iso-Dense Bias,IDB, laser bandwidth, E95, OPE

1. INTRODUCTION

With the introduction of ArF lithography into mass production, critical dimension (CD) control requirements are becoming tighter and Optical Proximity Correction (OPC) is becoming more complex. This complicated OPC is based on the premise that the Optical Proximity Effects (OPE) of the exposure tool do not vary, and therefore OPE must be controlled to within a fixed range to enable device volume manufacturing.

A factor which affects the exposure tool OPE variation is change in the bandwidth of the laser light source. When the bandwidth of the laser light source fluctuates, there is a greater impact from chromatic aberration already present in the optical system of the exposure tool, leading to focus blur. This results in a degradation of image contrast, leading to CD variation. This CD variation amount differs for dense and isolated patterns, causing a change in the Iso-Dense Bias (IDB) due to bandwidth fluctuation, ultimately resulting in a change in OPE.

With the dual aim of productivity improvement for 55nm Technology Device volume production and expediting 45nm Technology Device R&D, we have evaluated the influence of laser bandwidth stability on IDB. Additionally, we also investigated a method to adjust for OPE variation that occurs due to laser bandwidth fluctuation.

As a metric of laser light source bandwidth, we used E95 which represents the bandwidth that includes 95% of the spectral energy.

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Optical Microlithography XX, edited by Donis G. Flagello, Proc. of SPIE Vol. 6520, 652011, (2007)
0277-786X/07/$18 · doi: 10.1117/12.711052

2. ISO-DENSE BIAS (IDB) SENSITIVITY TO LASER SPECTRAL SHAPE

Initially, through simulation we evaluated the IDB sensitivity as estimated for 55nm Technology Node Device. The simulation was performed for 90nm line patterns and 100nm space patterns, assuming exposure on an ASML ArF Immersion Exposure Tool XT1400Ei. Varying E95 from 0.4pm through 0.7pm, we calculated the pitch dependency for 90nm line from pitch of 180nm through 1290nm, and for 100nm spaces with the pitch varied from 200nm to 1300nm. For each E95 setting, dose was adjusted for the densest pitch for line and spaces, respectively. The simulation results are shown in Table 1. Additionally, Iso-Dense Bias Sensitivity as obtained from the simulation for 90nm lines, and 100nm spaces are shown in Fig. 1 and Fig. 2, respectively.

Table 1. Simulation condition for 90 nm lines & 100 nm spaces

Item	Conditions
Exposure tool	XT1400Ei
CD	Based on aerial image threshold
Illumination	NA=0.93, Outer sigma=0.80, Inner sigma=0.50 (Ann)
Pattern	90nm Line : pitch=180 nm ~ 1290 nm 100nm Space : pitch=200 nm ~ 1300 nm
E95	0.4 pm ~ 0.7 pm
Dose	optimized for dense pattern for each E95

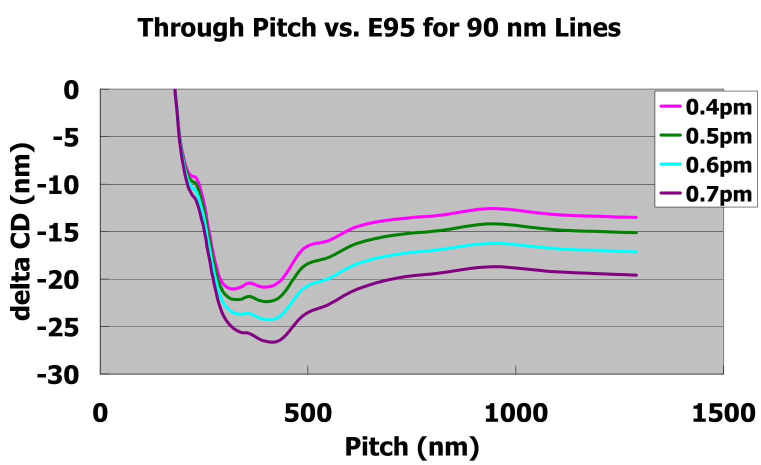

Fig. 1 Through Pitch vs. E95 for 90 nm Lines (Simulation)

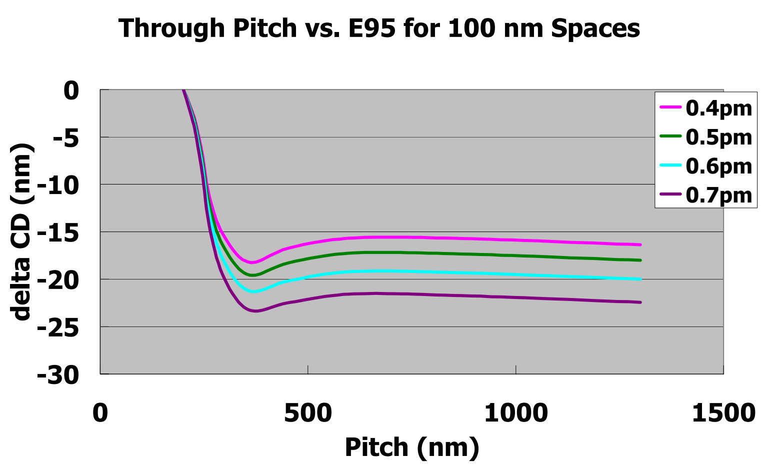

Fig. 2 Through Pitch vs. E95 for 100 nm Spaces (Simulation)

For both 90nm lines and 100nm spaces, as E95 becomes larger, the delta CD between isolated and dense patterns increases. These results are shown in Fig. 3.

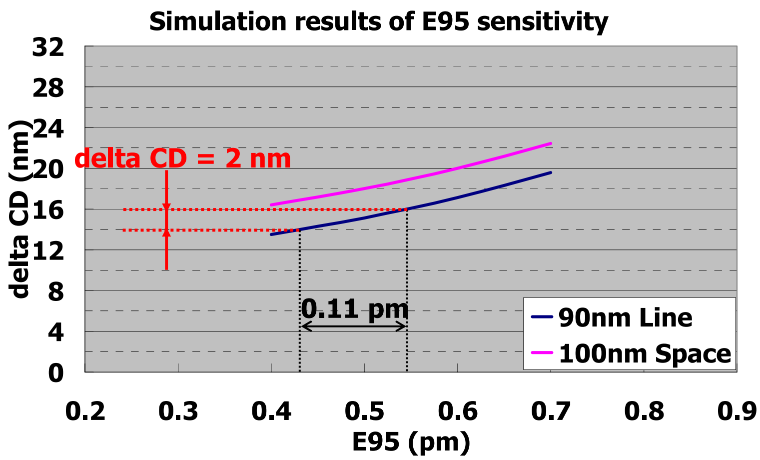

Fig. 3 Simulation results of E95 sensitivity

Based on these results, E95 stability of less than 0.11pm is required to control E95-induced IDB to within 2nm for both 90nm lines and 100nm spaces.

Next, we show experimental exposure results that verified IDB sensitivity as calculated by simulation. The E95 was set within a range from 0.4pm to 0.8pm. All other simulation conditions were identical to those of the simulation. The details of the experimental conditions are presented in Table 2. In addition, Iso-Dense Bias Sensitivity as obtained from actual exposure results for 90nm line, and 100nm space are shown in Fig. 4 and Fig. 5, respectively.

Table 2 Experimental Condition for 90 nm lines & 100 nm spaces

Item	Conditions
Exposure tool	XT1400Ei
Illumination	NA=0.93, Outer sigma=0.80, Inner sigma=0.50 (Ann)
Pattern	90 nm Line : pitch=180 nm ~ 1290 nm 100 nm Space : pitch=200 nm ~ 1300 nm
E95	0.4 pm ~ 0.8 pm
Dose	optimized for dense pattern for each E95
CD Measurement	CD SEM

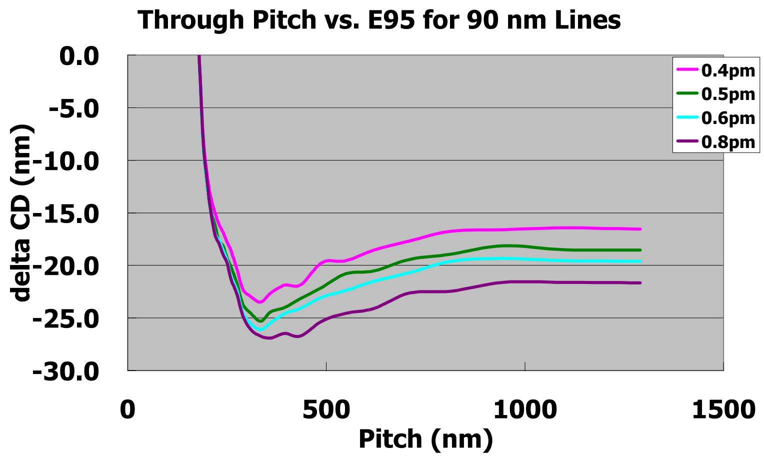

Fig. 4 Through Pitch vs. E95 for 90 nm Line (Experiment)

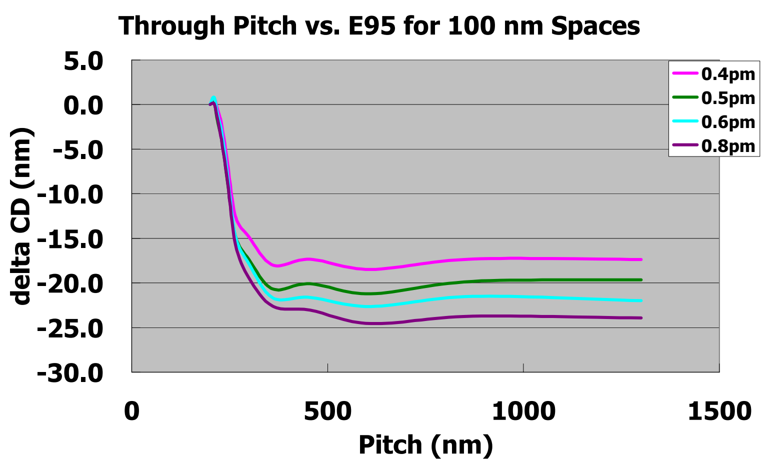

Fig. 5 Through Pitch vs. E95 for 100 nm Line (Experiment)

The experimental results exhibit a similar trend to that of simulation, whereby the delta CD between isolated and dense patterns increases as E95 increases. For both 90nm lines and 100nm spaces, the isolated line CD dimension is smaller when compared to the simulation, however, this is though to be a characteristic of the resist used for the experiment. Even considering this difference, a strong correlation has been established between experimental and simulation results. Fig. 6 shows IDB Sensitivity to E95 as calculated from experimental results.

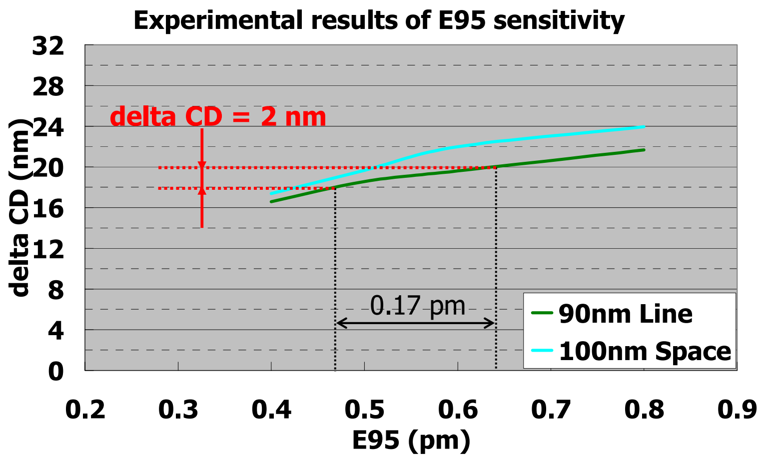

Fig. 6 Experimental results of E95 sensitivity

Based on the experimental results, for both the 90nm line and 100nm space, E95 stability less than 0.17pm is required in order to control E95-induced IDB variation to less than 2nm. Moreover, we have also confirmed the change in IDB Sensitivity as function of resist process.

Next, we show results that verify experimental results with those of simulation for OPE curve matching techniques when E95 varies. CD variation occurs as E95 worsens due to the loss of image contrast. Since poor E95 conditions cannot be matched to good conditions, the OPE curve matching is always adjusted to that of worse E95 condition.

Therefore, we initially verified with simulation the OPE curve matching adjusted using the conventional illumination sigma methodology. The simulation was performed by matching E95 of 0.3pm to that of 0.6pm IDB sensitivity curve. The simulation results are presented in Table 3. The OPE curve delta CD as obtained from simulation is shown in Fig 7.

Table 3 Simulation condition for sigma adjustment

Item	Conditions
Exposure tool	XT1400Ei
CD	Based on aerial image threshold
Illumination	NA=0.93, outer sigma=0.80 ~ 0.86, inner sigma=0.50 (Ann)
Pattern	90nm Line : pitch=180 nm ~ 1290 nm
E95	0.3 pm, 0.6 pm
Dose	optimized for dense pattern for each setting

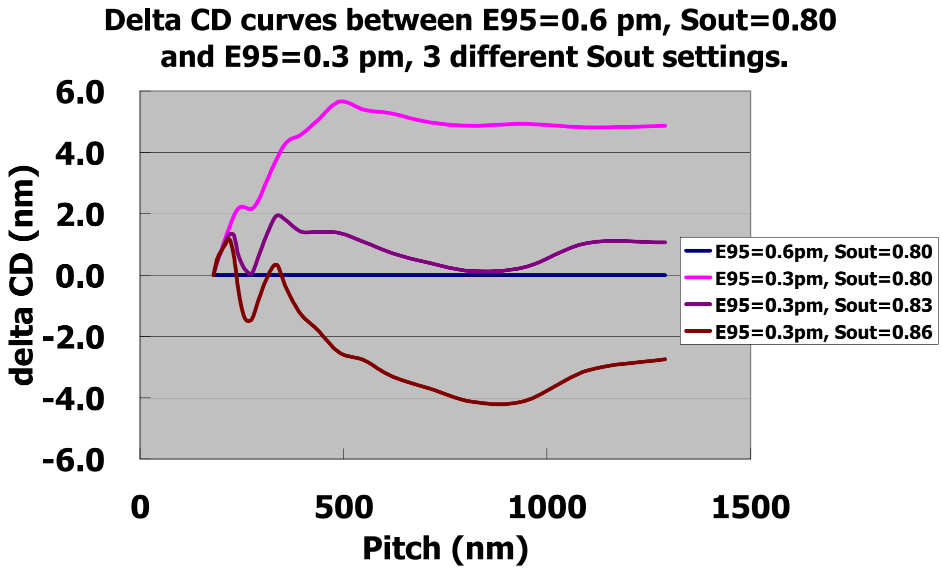

Fig. 7 Delta CD curves between E95=0.6 pm, Sout=0.80 and E95=0.3 pm, 3 different Sout settings

Fig. 7 shows the OPE Curve Delta CD for E95 of 0.3pm adjusted for multiple outer sigma conditions, where the reference is the OPE curve for E95 of 0.6pm and outer sigma of 0.80. These simulation results show that even with adjustment of outer sigma, there is a residual delta CD of 2nm. This indicates that the delta CD for actual exposure results may not be less than 2nm.

Due to the limitation of illumination sigma optimization alone to adequately adjust for E95-induced OPE delta, we have verified via simulation OPE curve matching through Contrast Adjustment (CA), which is a function to compensate for E95 variation on the exposure tool itself.

Here we explain the general outline of Contrast Adjustment. We are able to represent IDB as a function due to the system vibration $MSDS_{total}$, as shown in the following formula:

$$MSDZ_{total} = \sqrt{MSDZ_{E95}{}^2 + MSDZ_{Rx}{}^2 + others}$$

Since $MSDS_{total}$ is able to distinguish between $MSDS_{E95}$ -- the vibration component due to E95 -- and $MSDS_{RX}$ -- the component in the Z direction -- compared to the situation when $MSDZ_{E95}$ is reduced and IDB improved, a constant IDB can possibly be maintained by increasing $MSDS_{RX}$ based on the amount of change in $MSDS_{E95}$. Using Contrast Adjustment, $MSDS_{RX}$ control is accomplished by tilting the wafer and using a composite focus exposure method. The CA amount is defined as the amount of tilt specified. The principle of the composite focus exposure method is shown is Fig. 8.

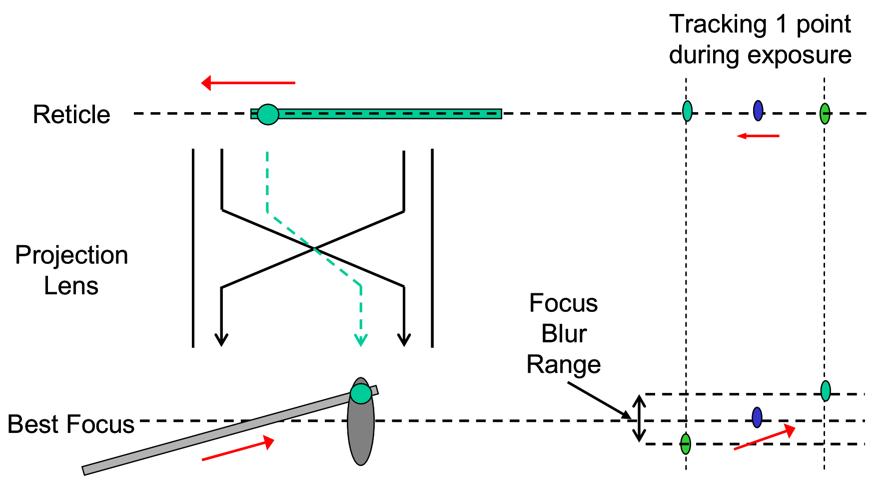

Fig. 8 Contrast Adjustment principle

The simulation using Contrast Adjustment was done by adjusting the IDB sensitivity of E95 of 0.4pm to that of E95 0.6pm. The simulation details are shown in Table 4. The OPE Curve Delta CD as determined from simulation is presented in Fig. 9.

Table 4 Simulation condition for Contrast Adjustment

Item	Conditions
Exposure tool	XT1400Ei
CD	Based on aerial image threshold
Illumination	NA=0.93, outer sigma=0.80, inner sigma=0.50 (Ann)
Pattern	90nm Line : pitch=180 nm ~ 1290 nm
E95	0.4 pm, 0.6 pm
Contrast Adjustment	0%, 22%, 45%, 67%, 90%
Dose	optimized for dense pattern for each setting

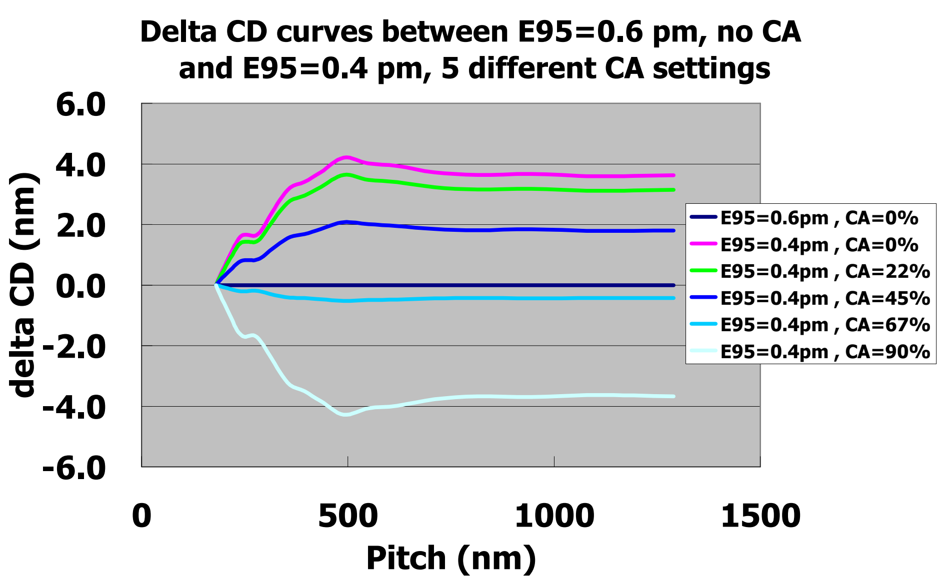

Fig. 9 Delta CD curves between E95=0.6 pm, CA=0% and E95=0.4 pm, 5 different CA settings

Fig. 9 shows the OPE Curve Delta CD for E95 0.4pm adjusted for multiple CA settings, with a reference of E95=0.6pm and CA=0%. These results indicate that the condition of E95=0.4pm and CA=67% maintains a delta CD of less than 0.5nm with respect to the reference of E95=0.6pm and CA=0%.

Through the OPE Curve Matching simulation using Contrast Adjustment, we have demonstrated that the OPE difference that exists because of E95 fluctuation can be alleviated through Contrast Adjustment. The validity of the Contrast Adjustment function was verified through actual experimental exposure. The experiment was performed using four (4) CA settings from 0% to 65%. All other conditions were equivalent to those of the simulation. The simulation details are shown in Table 5. Experimental test results are displayed in Fig. 10.

Table 5 Experimental condition for Contrast Adjustment

Item	Conditions
Exposure tool	XT1400Ei
Illumination	NA=0.93, outer sigma=0.80, inner sigma=0.50 (Ann)
Pattern	90nm Line : pitch=180 nm ~ 1290 nm
E95	0.4 pm, 0.6 pm
Contrast Adjustment	0%, 40%, 50%, 65%
Dose	optimized for dense pattern for each setting

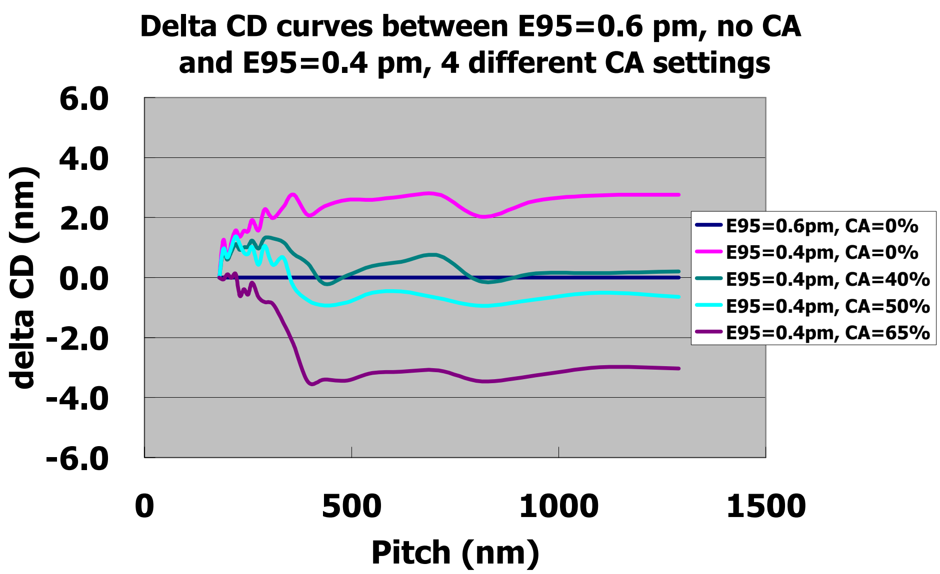

Fig. 10 Delta CD curves between E95=0.6 pm, CA=0% and E95=0.4 pm, 4 different CA settings

Fig. 10 shows the experimental OPE Curve Delta CD for E95=0.4pm adjusted to multiple CA settings, with a reference of E95=0.6pm and CA=0%.

The experimental exposure results demonstrate that OPE Curve Delta can be adjusted to less than 2nm using Contrast Adjustment.

However, the Contrast Adjustment simulation results showed an optimal condition of CA=67%, whereas CA=67% was the optimal setting for actual exposure. The delta that exists between simulation and actual is thought to be due to the spectral shape. In the simulation, the laser spectral shape is calculated as a Gaussian distribution. An example of the actual laser spectral shape is shown in Fig. 11. In reality, the actual laser spectral shape is not a Gaussian distribution, but rather changes with E95 variation.

The delta between simulation and experimental results is thought to be due to the difference in the laser spectral shape. Therefore, by using actual laser spectral shape data will increase the simulation accuracy.

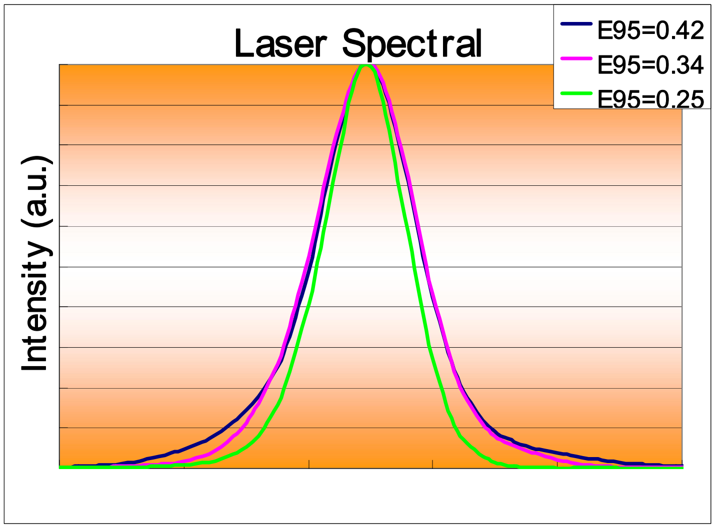

Fig. 11 Laser Spectral Shape for various E95

3. IDB SENSITIVITY AT 45NM NODE

Next, we present IDB Sensitivity simulation results estimated for the 45nm Technology Node Logic Device. The simulation used 65nm line pattern, with exposure on an ASML ArF Immersion Exposure Tool, XT1700Fi. The simulation details are presented in Table 6. Fig. 12 shows 65nm line IDB Sensitivity as determined from the simulation.

Table 6 Simulation condition for 65 nm lines

Item	Conditions
Exposure tool	XT1700Fi
CD	Based on aerial image threshold
Illumination	NA=1.20, outer sigma=0.86, inner sigma=0.66 (Ann)
Pattern	65 nm Line : pitch=130 nm ~ 760 nm
E95	0.3 pm ~ 0.7 pm
Dose	optimized for dense pattern for each E95

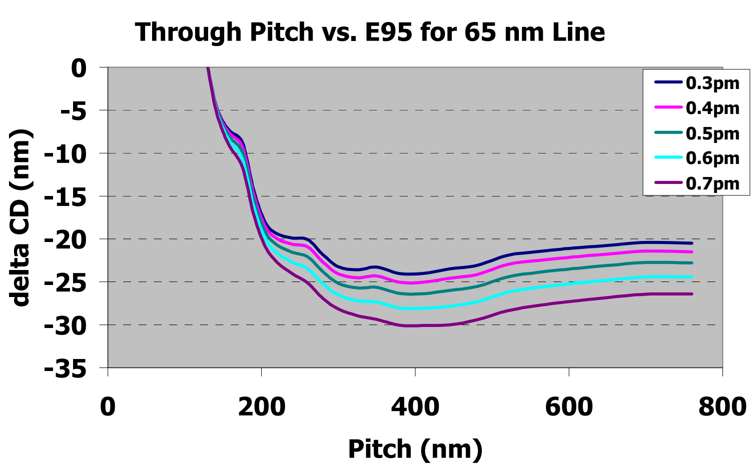

Fig. 12 Through Pitch vs. E95 for 65 nm Lines (Simulation)

Similar to the trend found for 90nm line and 100nm space patterns, as E95 becomes larger, the delta CD between dense and isolated feature increases. The IDB sensitivity with respect to E95 as determined from the simulation results is shown in Fig. 13.

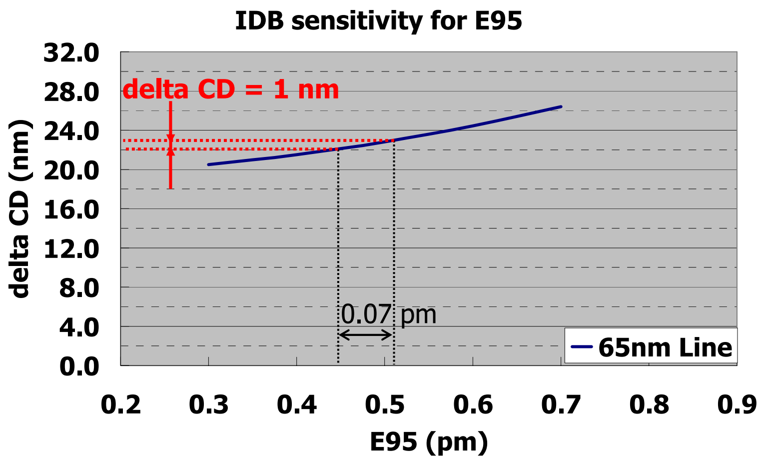

Fig. 13 Simulation results of E95 sensitivity

Based on these results, E95 stability less than 0.07pm is required in order for E95-induced IDB variation to be controlled to less than 1nm.

With respect to the simulation results, we confirmed the laser light source E95 stability and its impact on OPE. Fig. 14 shows the E95 stability of the Cymer laser light source XLA 360. The XLA 360 is set to the simulation condition of a laser light source for usage with XT1700Fi. XLA 360 E95 stability range over an eight week period was under 0.03pm, satisfying the 0.07pm requirement as determined by simulation results. From these results, it is shown that OPE variation will be less than 1nm when using XLA 360 laser light source.

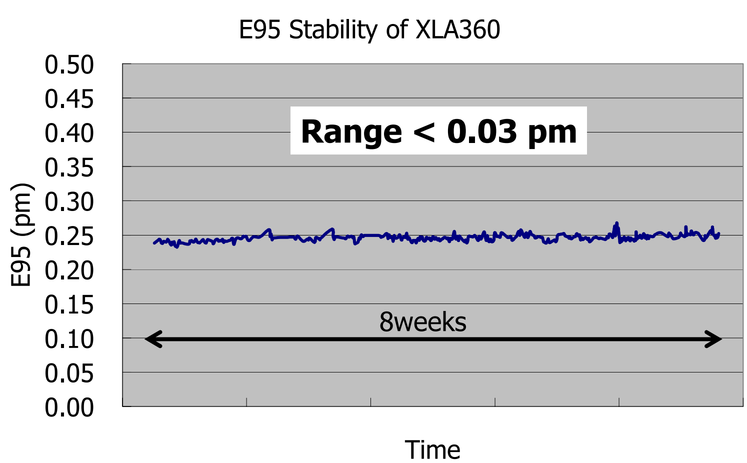

Fig. 14 E95 Stability of XLA 360

4. CONCLUSION

Through both simulation and experiment, we have evaluated the impact of E95 fluctuation on IDB. Through optical simulation, we have determined that in order to maintain OPE variation to less than 2nm for 55nm logic device, E95 stability less than 0.11pm is required. Similarly, experimental results also show that E95 stability less than 0.17pm is necessary.

In addition, we evaluated, using both simulation and experiment, the feasibility of OPE curve matching when E95 fluctuates. Simulation results show that when using conventional illumination sigma adjustment for OPE curve matching, there is still a 2nm residual OPE curve difference. By using the Contrast Adjustment function, simulation results show that OPE curve difference can be maintained to less than 0.05pm when performing OPE curve adjustment. Moreover, we have demonstrated that usage of Contrast Adjustment can limit delta in OPE curves to less than 1.5nm.

Next, we evaluated through simulation the impact of E95 fluctuation on IDB for 45nm logic device patterns. We have shown that in order to maintain E95-induced OPE variation to less than 1nm, E95 stability of less than 0.07pm is required.

Furthermore, XLA 360 E95 stability is less than 0.03pm, thereby allowing OPE variation to be maintained to within 1nm.

5. ACKNOWLEDGMENT

The authors would like to acknowledge James F. Bonafede of Cymer for his assistance in this work, and to thank Shuichi Inoue and Hidenobu Miyamoto for their continuous encouragement. Finally we also would like to give a special thank to all the people who contributed towards the achievement of this work.

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